Forest Sci., Vol. 28, No. 4, 1982, pp. 706–710

Formation of Mycorrhizae on Nonmycorrhizal Western Hemlock Outplanted on Rotten Wood and Mineral Soil

Bradley R. Kropp

ABSTRACT. Formation of mycorrhizae on nonmycorrhizal western hemlock (*Tsuga heterophylla*) seedlings was examined in two separate outplanting studies in western Oregon. In both studies, seedlings were readily colonized by indigenous mycorrhizal fungi. In the first study, the number of short roots colonized by mycorrhizal fungi gradually increased through the season from a few in the first 2–3 months to nearly total colonization by fall. In the second study, mycorrhizal colonization readily took place on seedlings planted in both rotten wood and mineral soil on two different clearcuts. The same total percentages of short roots became colonized in rotten wood and mineral soil. Some mycorrhizal fungi occured in both rotten wood and soil, but others occurred only in one or the other substrate.

Hemlock seedlings survived and grew well on both rotten wood and mineral soil during the first growing season after outplanting. On the most recent clearcut, however, seedling growth at the end of the season was significantly greater on mineral soil than on rotten wood. No other differences were observed. FOREST SCI. 28:706–710.

ADDITIONAL KEY WORDS. *Tsuga heterophylla, Cenococcum geophilum,* reforestation, fungi.

WESTERN HEMLOCK (*Tsuga heterophylla* (Raf.) Sarg.) is an important component of timber producing forests in coastal regions of the Pacific Northwest. It generally seeds successfully into clearcuts to produce full or overstocked stands (Ruth and Harris 1973). Hemlock does well on a variety of natural seedbeds (Ruth and Harris 1973, Williamson 1976), including well-decayed wood in coastal areas. Berntsen (1955) found that on one clearcut, rotten wood (42 percent of the total plot area) was 97 percent stocked, whereas mineral soil (26 percent of the total plot area) was 83 percent stocked. The rotten wood had provided an excellent seedbed for trees but a poor one for competing vegetation.

Berntsen (1960) found that survival of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) planted on rotten wood was as good as on soil in a clearcut in a high rainfall area. Growth was also as good or better on rotten wood than on soil. He concluded that planting on either rotten wood or mineral soil is a sound practice in coastal areas with an average of 25 cm growing season precipitation. Wasteful openings created when planters avoid rotten wood are prevented. Rotting logs from five different log decay classes covered a total of 13.2 percent of an old-growth Douglas-fir ecosystem in the western Cascades (K. Cromack, Dep. Forest Science, Oregon State Univ., Corvallis, OR 97331, personal communication). Faster growth of seedlings on rotten wood might result from the relative freedom from competing vegetation.

Natural hemlock seedlings are mycorrhizal whether growing on soil or rotten wood (personal observation). The manner and rate at which outplanted, nursery grown seedlings become mycorrhizal, however, is largely unknown. In light of recent interest in inoculating nursery seedlings with mycorrhizal fungi, it is useful to examine the mycorrhizal colonization of uninoculated nursery seedlings after outplanting.

This study had two objectives: (1) To make observations, during one growing season, on the general pattern and rate at which native fungi colonize outplanted nonmycorrhizal western hemlock seedlings on a 6-year-old clearcut, and (2) To further explore these observations during another growing season by comparing survival, growth, and mycorrhizal colonization of seedlings planted in decayed wood versus mineral soil.

This paper is part of a thesis for the author's Ph.D. degree at Oregon State University, Department of Botany and Plant Pathology, Corvallis, OR 97331. These studies were funded by Crown Zellerbach Corporation in cooperation with the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, OR 97331. Manuscript received 10 December 1980.

Materials and Methods

The study consisted of two separate outplantings; one done in 1978 and the other in 1979. Both outplantings were conducted at Mary's Peak in the Siuslaw National Forest in western Oregon. The sites used are on the eastern edge of the Coast Ranges at about 750 m in elevation. They receive an average of about 13 cm of precipitation during the May–August growing season.

1978 Outplanting.—In mid-April, 109 1-year-old containerized western hemlock obtained from the Crown Zellerbach Corporation nursery at Aurora, Oregon, were planted at a 3- × 3-foot spacing in a 6-year-old clearcut. Each seedling was examined visually before being planted to determine that it was nonmycorrhizal. The soil on this site was a deep well-drained gravelly clay loam in the Klickitat series. Beginning with the 2d week after planting, five randomly selected seedlings were carefully excavated by hand and examined every 2 weeks until the end of October. Observations were recorded for each seedling for (a) presence or absence of mycorrhizae, and (b) general pattern of mycorrhizal colonization.

1979 Outplanting.—One-year-old containerized hemlock seedlings were obtained from the Crown Zellerbach Corporation nursery at Aurora, Oregon, in mid-February 1979 and stored in plastic bags at about 1°C until being outplanted at the end of April 1979. Each tree was visually examined to insure that it lacked mycorrhizae before planting. The trees were planted on two different clearcuts. One had been harvested in winter 1977 and the slash burned in fall 1978. This clearcut was on a deep, well-drained gravelly loam in the Slickrock series. The other was the same clearcut used in the 1978 study.

Five pairs of plots were planted on each of the clearcuts. Each plot contained 10 seedlings. One plot of each pair was on well-decayed rotten wood which was being naturally incorporated into the soil. The majority of these rotten wood plots were well defined (consisting completely of rotten wood and having a definite boundary between the wood and soil). Several consisted of the remains of entire logs into the full length of which trees could be planted. The other plot of each pair was planted in mineral soil adjacent to the rotten wood. The spacings between plot pairs and between seedlings varied in order to insure that seedlings were planted in only rotten wood or soil rather than in a mixed substrate. Plot size also varied according to the area covered by each patch of rotten wood. The plots were mapped, and the trees on each plot numbered from 1–10. Half of the trees were randomly selected for careful manual excavation and evaluation in July. The remainder were excavated at the end of November 1979.

The percentage of short roots of each tree that became colonized by mycorrhizal fungi was estimated by stereomicroscopic scanning in a five-class system: one = 0–10 percent, two = 10–25 percent, three = 25–50 percent, four = 50–75 percent, five = 75–100 percent. Root growth was evaluated as the mean length of the five longest roots newly grown from the root plug, and the current year's leader growth was measured in centimeters. Each type of mycorrhiza was briefly described (Table 1), and the types present on each seedling were recorded. Mycorrhiza types were separated on the basis of color and morphology. An analysis of variance was used to evaluate differences between the effects of rotten wood and mineral soil on seedling growth and mycorrhizal colonization.

Results and Discussion

In the 1978 outplanting, the first mycorrhizae (a white type) appeared on three of the five seedlings examined in June, 2 months after planting. At 3 months, black mycorrhizae, formed with *Cenococcum geophilum* Fr., began to appear. Every seedling examined had formed mycorrhizae by 3½ months, although some root systems were sparsely colonized, having developed less than 10 mycorrhizae. By 5½ months, mycorrhizal fungi had colonized nearly 100 percent of the short roots on most trees.

Since by the end of the season most seedlings were thoroughly colonized, mycorrhizal inoculum appears to have been abundant on this site. Some of the fungi appear to have occurred in pockets, since some trees were observed to be colonized by only one of several types of fungi. This point is also supported by the fact that the roots of some seedlings were covered in one portion by one type of mycorrhiza and in another portion by mycorrhizae of a different color or morphology.

TABLE 1. Brief description of mycorrhiza types.

Type	Mantle color	Branching pattern	Rhizomorphs	Other comments
a	tan	unbranched	–	appear nonmycorrhizal macroscopically
b	black	unbranched	–	formed with *Cenococcum geophilum*
c	white/tan	branched	–	smooth mantle; rootlets swollen and gnarled
d	gray/tan	unbranched	–	smooth mantles
e	tan	unbranched	–	smooth mantle; no grayish hues
f	white	unbranched	+	mantle minutely rough; no tan hues
g	whitish over tan	branched	–	smooth mantle; whitish mycelium visible on roots
h	gray/tan	rarely branched	–	smooth mantle; rootlets long, slightly twisted
i	tan	highly branched	–	smooth mantle; rootlets long, in dense clusters
j	yellow/ochre	highly branched	–	rootlets plump, in dense clusters
k	yellow/green	highly branched	+	rootlets plump

Trees that had been planted by chance in buried rotten wood developed mycorrhizae on nearly 100 percent of the short roots available. This led to the hypothesis that rotten wood in clearcuts (some possibly being from old nurse-logs) could serve as a reservoir of mycorrhizal inoculum for western hemlock. This hypothesis is supported by the data of Harvey and others (1976). They found that decayed wood supports a substantial portion

TABLE 2. Mean values for root growth, leader growth, survival, and mycorrhiza class from the 1979 outplanting.[a]

Item	Month	Recent clearcut		Old clearcut	
		Rotten wood	Mineral soil	Rotten wood	Mineral soil
Root growth (cm)	July	11.23	9.39	11.75	9.98
	Nov.	16.33	16.54	13.37	11.96
Leader growth (cm)	July	5.20	6.14	6.66	5.52
	Nov.	12.55	18.59	9.49	7.76
Survival[b]	Nov.	4.6	4.8	4.4	4.4
Mycorrhizal class[c]	July	1.55	1.19	1.12	1.28
	Nov.	4.80	4.92	4.22	4.23

[a] Analysis of variance shows leader growth in the November sample on the recent clearcut to be significantly greater for trees on mineral soil (0.05 level). No other means differed significantly between rotten wood and mineral soil within either clearcut in July or November.

[b] Mean survival figures are for the five trees left for the November sample on each of the five plots.

[c] Mean mycorrhiza classes are based on a visual estimate of the percent of short roots colonized for each tree: 1 = 0–10 percent, 2 = 10–25 percent, 3 = 25–50 percent, 4 = 50–75 percent, 5 = 75–100 percent.

TABLE 3. Number of seedlings on which each mycorrhiza type was found in the 1979 outplanting.

Mycorrhiza type	Substrate[a]	Recent clearcut		Old clearcut	
		July	November	July	November
a	RW	7[b]	5	9	5
	MS	10	—	4	7
b[c]	RW	4	19	7	18
	MS	17	23	11	23
c	RW	9	10	2	—
	MS	—	1	—	1
d	RW	2	1	5	4
	MS	7	—	7	8
e	RW	—	10	3	11
	MS	—	4	4	6
f	RW	—	—	1	1
	MS	—	—	5	4
g[d]	RW	—	2	—	2
	MS	—	—	—	3
h	RW	—	12	—	5
	MS	—	23	—	5
i	RW	—	3	—	2
	MS	—	—	—	—
j	RW	—	—	—	—
	MS	—	—	—	2
k	RW	—	—	—	1
	MS	—	—	—	—

[a] RW = rotten wood; MS = mineral soil.

[b] The number of trees out of a total of 25 (5 per plot in most cases except where trees had not survived) sampled at each time.

[c] Formed with *Cenococcum geophilum*.

[d] Types g through k colonized seedlings more slowly, appearing only after the July sample.

of the total number of ectomycorrhizae in the Douglas-fir/larch stands in Montana and that rotten wood supports more mycorrhizal activity than other soil fractions during the drier parts of the growing season (Harvey and others 1978). Harvey and others (1979) found that mycorrhizae were concentrated in decayed wood through the growing season on a site with a chronic moisture deficit.

The 1979 outplanting was designed to test the hypothesis that rotten wood is a reservoir of mycorrhizal inoculum for western hemlock seedlings and to compare 1st-year survival and growth on rotten wood with that on mineral soil. In the 1979 planting, leader growth (cm) of the seedlings on mineral soil was significantly greater than growth on rotten wood for the recent clearcut. This difference was not observed at midseason. No leader growth differences occurred on the old clearcut between substrates either midseason or at season's end (Table 2). No root growth (cm) differences were found in the experiment. Survival did not differ significantly between the substrates or clearcuts when evaluated in November. Seedlings planted in rotten wood became mycorrhizal. Thus, decayed wood does appear to serve as a reservoir for hemlock mycorrhizal fungi. Percent formation of mycorrhizae at mid- and end of season did not differ significantly between substrates (Table 2).

Most types of mycorrhizae formed both in rotten wood and mineral soil, although some occurred only in one substrate or the other (Table 3). Types i and k occurred only in

rotten wood, whereas type j occured only in mineral soil. These types, however, were found on only a small number of trees. Type c was more common and occurred entirely in rotten wood except for two trees in soil. Type f occurred primarily on trees in soil although two trees in decayed wood did form this type of mycorrhiza. Some trees planted in wood either came partially in contact with mineral soil or had roots which grew out into mineral soil, thus encountering both mineral soil and rotten wood fungi. The number of mycorrhiza types did not differ markedly between rotten wood or soil, although number of types in both environments increased between mid- and end of the season. Most mycorrhiza types occurred on both the young and the old clearcuts. Types f, j, and k were seen only on the old clearcut area.

Overall, type b, formed with *Cenococcum geophilum,* predominated. At the time of the midseason sample, it had formed mycorrhizae with only a few trees in rotten wood as compared to mineral soil on both the young and old clearcuts. By the end of the experiment, as many trees in wood had *Cenococcum* mycorrhizae as in soil.

In summary, during the first field season, containerized nonmycorrhizal western hemlock seedlings survived and grew well when planted on both rotten wood and mineral soil. Although there was a decrease in leader growth on one clearcut, those seedlings were healthy and not stunted. There appears to be little reason to avoid planting western hemlock on rotten wood. This concurs with Berntsen's (1960) results with Douglas-fir and Sitka spruce. The site on which our experiment was done receives considerably less average rainfall during the growing season than the site used by Berntsen (about 13 as opposed to 25 cm), indicating that rotten wood may be a suitable medium for planting on somewhat drier sites than was suggested in his paper. Because of the often cubical structure of rotten wood, extra care may be needed in planting seedlings in wood to avoid leaving air spaces around the root plug which would increase mortality.

Mycorrhizae formed quite rapidly on nonmycorrhizal seedlings planted in these Coast Range sites. Observations from the 1978 study indicate that colonization gradually increased through the season from a few in the first 2–3 months to nearly total colonization by fall. Mycorrhizal colonization appears to occur equally well in rotten wood and mineral soil.

Literature Cited

Berntsen, C. M. 1955. Seedling distribution on a spruce-hemlock clearcut. USDA Forest Serv, Pac Northwest Forest and Range Exp Stn Res Note 119, 7 p.

Berntsen, C. M. 1960. Planting Sitka spruce and Douglas-fir on decayed wood in Coastal Oregon. USDA Forest Serv, Pac Northwest Forest and Range Exp Stn Res Note 197, 5 p.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1976. Distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in western Montana. Forest Sci 22:393–398.

Harvey, A. E., M. F. Jurgensen, and M. J. Larsen. 1978. Seasonal distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in western Montana. Forest Sci 24:203–208.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1979. Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat-types. Forest Sci 24:350–358.

Ruth, R. H., and A. S. Harris. 1973. Western hemlock-Sitka spruce. *In* Silvicultural systems for the major forest types of the United States, p 5–7. U S Dep Agric, Agric Handb 445, 114 p.

Williamson, R. L. 1976. Natural regeneration of western hemlock. *In* Proc western hemlock management conference, p 166–169. Coll Forest Resour, Univ Wash, Seattle.